Optical Disc Authentication Method and Apparatus

Field of the Invention

The present invention relates to digital storage devices, and more particularly to optical disc authentication.

Background of the Invention

The popularity of the optical storage disc has risen dramatically since its introduction in the early 1980's. Optical discs, typically referred to as "CDs" (compact disc), "CD-ROMs" (compact disc read-only memory) and more recently "DVDs" (digital versatile disc), have increasingly enjoyed wide acceptance within several industries. Manufacturers have been quick to adopt the format, regularly employing optical discs in the distribution of products such as music and computer software due to their ability to provide virtually error-free duplication.

However, in large part because of these very advantages, companies are increasingly faced with the illegal copying and distribution of copyrighted material. The problem has only been exacerbated by an enormous increase in the accessibility of duplicating equipment due to recent technical advances that have lowered their cost.

In an effort to discourage illegal copying, methods have been attempted to differentiate an original disc from an illegally copied one. The most common technique for optical disc authentication has been to write distinguishing marks on the disc along with the product data. These distinguishing marks are made to be difficult to correctly copy onto a disc, or include information relating to a physical location on the disc.

Another technique is to embed an identifier in the appended parity

bytes that are used for detecting and correcting errors in data frames. Still another technique provides a unique serial number that software can verify with a password contained within the product data.

However, these methods have typically required laborious additional steps within the mastering process, and lack a format-insensitive solution.

For the foregoing reasons, there is a need for an improved method of optical disc authentication.

Summary of the Invention

The present invention is directed to an optical disc authentication method and apparatus. The method, wherein each disc has a plurality of ways and a plurality of sectors in each way, includes the steps of measuring the quantity of sectors in each of a defined quantity of ways to provide a disc fingerprint comprising way sector quantity values for an original disc and a target disc and authenticating the target disc.

The step of authenticating the target disc includes the steps of comparing the target disc fingerprint to the original disc fingerprint to determine a percentage of coinciding way sector quantity values and classifying the target disc according to whether its determined percentage value is above or below a pre-defined percentage threshold value, wherein a target disc having a determined percentage value of greater than or equal to the threshold value is classified as an original disc, and a target disc having a determined percentage value of less than the threshold value is classified as an illegally copied disc.

In an aspect of the present invention, the measuring step includes the steps of determining optical disc drive characteristics, collecting sector reading time data and processing the collected data to provide way sector quantity values.

In an aspect of the present invention, the optical disc drive characteristics are determined by determining cache buffer memory size of the disc drive and determining reading speed reduction parameters of the disc drive.

In an aspect of the present invention, the sector reading time data is collected by filling the cache buffer with blank data and collecting reading time data in a reading time array from a defined quantity and location of ways on a disc.

In an aspect of the present invention, the collected data is processed by filtering the data to compensate for reading errors, determining a common slope from the filtered data and identifying slopes matching the determined common slope to ascertain individual ways for the measurement of way sector quantity values.

Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

Brief Description of the Drawings

These and other features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings where:

Figure 1a is an overview of an optical disc authentication method according to the present invention;

Figures 1b-1e show embodiments of the optical disc authentication method according to the present invention;

Figures 2a and 2b show a flowchart of an optical disc authentication method according to the present invention;

Figure 3 shows a reading time array;

Figure 4 is a representation of a top view of an optical disc showing a sector reading sequence;

Figure 5 is a graph of raw sector reading time data;

Figure 6 is a graph of filtered sector reading time data; and

Figure 7 shows a sector quantity array.

Detailed Description of the Presently Preferred Embodiment

The present invention is directed to an optical disc authentication method and apparatus. As shown in Figure 1a, the method, wherein each disc has a plurality of ways and a plurality of sectors in each way, includes the

steps of measuring the quantity of sectors in each of a defined quantity of ways to provide a disc fingerprint comprising way sector quantity values for an original disc and a target disc 12 and authenticating the target disc 14.

The step of authenticating the target disc 14 includes the steps of comparing the target disc fingerprint to the original disc fingerprint to determine a percentage of coinciding way sector quantity values 16 and classifying the target disc according to whether its determined percentage value is above or below a pre-defined percentage threshold value, wherein a target disc having a determined percentage value of greater than or equal to the threshold value is classified as an original disc, and a target disc having a determined percentage value of less than the threshold value is classified as an illegally copied disc 18.

As shown in Figure 1b, in an embodiment of the present invention, the measuring step 12 includes the steps of determining optical disc drive characteristics 20, collecting sector reading time data 22 and processing the collected data to provide way sector quantity values 24.

As shown in Figure 1c, in an embodiment of the present invention, the optical disc drive characteristics are determined by determining cache buffer memory size of the disc drive 26 and determining reading speed reduction parameters of the disc drive 28.

As shown in Figure 1d, in an embodiment of the present invention, the sector reading time data is collected by filling the cache buffer with blank data 30 and collecting reading time data in a reading time array from a defined quantity and location of ways on a disc 32.

As shown in Figure 1e, in an embodiment of the present invention, the collected data is processed by filtering the data to compensate for reading errors 34, determining a common slope from the filtered data 36 and identifying slopes matching the determined common slope to ascertain individual ways for the measurement of way sector quantity values 38.

Data is recorded on an optical disc in a process called "mastering". The first stage in the mastering process involves the recording of product data onto an original disc known in the industry as a "gold master". The data is recorded on the disc in the form of a spiral path called a "trace" that starts

from the inside edge of the disc and winds its way towards the outer edge and is made up of sectors containing "pits" representing "1s" and "hills" representing "0s".

A specialized decoding machine copies the data from the gold master to a "master" disc. The master disc is then electrochemically plated with a thick layer of metal that, when separated from the master, provides a negative of the master known as a "stamper". Stampers are then used for disc duplication.

Disc duplicates have geometric structures that are virtually identical to the geometric structures of their respective masters. However, duplicates created from different masters differ due to sector writing deviations on the masters. These deviations are created by factors such as noise, loss of accuracy in laser placement control or change in disc rotation speed directly affecting the division of data into sectors.

These deviations take the form of a physical displacement of the pits and hills along the length of the trace resulting in a deviation in the physical length of the sector, so that even two master discs with identical binary information and produced on the same machine from the same gold master are different. This displacement can be especially pronounced in certain portions of the master disc, particularly at its outer edge due to error accumulation.

Therefore, since a direct relationship exists between a sector's reading time and its physical length, the invention collects reading time data to measure differences in sector lengths.

In an embodiment of the present invention, cache buffer memory size is determined from a cache size algorithm 42, shown in Table 1. The cache size algorithm 42 measures cache buffer memory size in relative single sector units. Cache buffer memory is contained in a memory chip installed on the logic board and serves as a storage area for data ready to be sent to the computer's microprocessor.

Table 1

```
CACHE_SIZE=100;
```

```
ReadSector(0,1,NULL);
ReadSector(0,1,&time);
cachetime=time;
for(i=CACHE_SIZE;i>0;i-=2)
{
    ReadSector(0,i,NULL);
    ReadSector(0,1,&time);
    if (time<2*cachetime)break;
}
//Total cache size
cachesize=i;
```

Since the buffer would alter the reading time results if reading time data were allowed to run through it, while reading the cache buffer memory is filled with blank data to allow reading time data to bypass it to provide a direct "flow-through" of information enabling reading time measurement in real time.

As well, since higher speeds tend to result in more errors, drives employ reading speed reduction to help reduce reading errors. Since parameters differ between drives, to compensate for altered results that may occur due to differing drive parameters, a reading speed reduction parameter algorithm is employed in the reading speed reduction parameters determination step 26 to determine the drive's reading speed reduction parameters.

In the data collection step 20 a "reading time algorithm" is employed for populating a "reading time array" 44, shown in Figure 3, with sector reading time data. The reading time array includes a sector number column 46 and a reading time column 48.

Since authentication accuracy is directly proportional to the quantity of sectors tested, the more sectors that are tested the more accurate the result. In compromising between speed and accuracy, it has been found through experimentation that an appropriate quantity of test sectors is at least about 1000, translating into roughly 50 turns or "ways", a way being defined as one complete turn of the trace.

In the data collection step 20, a "base sector" is designated and reading time measurements are taken from the base sector to each subsequent test sector in sequence towards the disc center. Reading time is defined as the sum of two time elements; the time it takes for the head to move from the base sector to a sequential sector and the time it takes to read the sequential sector. For example, as shown in Figure 4, a disc having a base sector designated as Sector 18 or S18 would have a reading sequence of S18,S17; S18,S16; S18,S15 --S18,S01.

As shown in Figure 5, the graphed raw data from the reading time array appears as a zigzagged line, the F-axis representing reading times and the Z axis representing sector numbers. The line contains erratic peak-anomalies or "leaps" 50 that appear on the right-hand slopes of the line reflecting sector-reading errors caused by factors such as disc damage.

To improve accuracy, the data is filtered to compensate for these factors using a filtering algorithm 52 shown in Table 2. The algorithm removes anomalies between the upper and lower ends of the right hand slopes of the line so that it no longer containing leaps as shown in Figure 6.

Table 2

$Y_{i-1}<Y_i>Y_{i+1}$; where $Y_{i-1}>Y_{i+1}$

```
for(i=1;i<SEEK_SECTOR-1;i++)
 {
if(time[i-1]<time[i]&&time[i+1]<time[i-1])time[i]=(time[i-
                    ]+time[i+2])/2;
}
```

where:

i is used for tracking the data

Yi represents the raw data

Once the data has been filtered, individual ways are discerned by determining a common slope for the majority of peaks employing a common slope algorithm 54 shown in Table 3.

Table 3

```
double k=0;
       int count=0;
```

```
for(i=0;i<SEEK_SECTOR-1;i++)
{
            if(time[i+1]<time[i])
{
k+=time[i+1]-time[i];
count++;
            }
}
k =k / count;
```

where:

k represents the slope of the curve

Employing a matching slope algorithm 58 shown in Table 4, the reading time fields 56 of the reading time array 44 are parsed to identify slopes matching the determined common slope 46 to ascertain individual ways.

Table 4

```
for(i=0;i<SEEK_SECTOR-2;i++)
 {
  double pp=(time[i+2]-time[i])/2;
  if(fabs(1-pp/k)>0.2)continue;
  for(j=i+3;j<SEEK_SECTOR;j++)
  {
   if(time[j]<time[j+1])break;
   double pz=(time[j]-time[i])/(j-i);
   if(fabs(1-pz/k)>0.2)break;
   pp=pz;
  }
     //forming the line equation
  line.k=pp;
  line.b=-pp*i+time[i];
  i=j;
     //adding a line to the base of lines
  Add(line);
 }
```

where:

i represents raw data

j is for tracking the sequence of the data

The data stored in the reading time array 44 is then utilized for measuring the quantity of sectors in each way employing a sector quantity algorithm 60 shown in Table 5.

Table 5

```
startsector = START_SECTOR //0x40000
    for(int i=0;i<1000;i++)
    {
    ReadSector(startsector,1,buffer,tmp);
    ReadSector(startsector-i-1,1,buffer,time[i]);
    }
    where:
    i represents raw data
```

As shown in Figure 7, measured sector quantity data is stored in a sector quantity array 62, which includes a way number column 64 and a sector quantity column 66. The sector quantity array 62 is used for establishing a pattern or "fingerprint" for the disc. To determine a target disc's authenticity, its fingerprint is compared to a fingerprint of an original disc provided in the form of a CD-Key.

To allow for differences that occur in duplicates due to wear and tear on stampers during the printing process, the optimal permissible percentage differentiation between disc fingerprints was established during experimentation to be less than or equal to about 30 percent. This "threshold value" provides a compromise between allowing for stamper wear and tear and detecting as many illegally copied discs as possible.

Therefore, taking into consideration the threshold value of 30 percent, the target disc should be considered to be an original disc if the percentage of coincidence is established to be greater than or equal to about 70 percent. Conversely, the target disc should be considered to be a counterfeit copy if the percentage of coincidence is established to be less than about 70 percent.

The invention uses a standard CD-ROM drive to exploit the deviations that occur due to differences between drives when discs are illegally copied.

In addition to regular CDs, the invention can be implemented for CD-Recordable (CD-R) discs since CD-Rs are pre-marked with empty sectors to enable proper synchronization of data during the final recording stage.

CD-R discs are made in batches produced from the same master, therefore having the same geometric structure. The mastering process determines the structure of a CD-R in the same manner as regular CDs, pre-determining the physical length of sectors even though product data has not yet been recorded so that even if data is burned onto separate CD-R discs using different equipment, as long as the discs are from the same batch, the differences that would typically exist either would not be detected using a standard drive or would not reach the 30% threshold.

In an embodiment of the present invention, to protect a non-recordable optical disc using the authentication method, a CD publisher provides core data locally and connects remotely to a "protection" website to run a remote copy of a protection program on the publisher's computer. The "core" data is encrypted and a protective "shell" added surrounding the core data. CD's are then made and a fingerprint is provided in the form of a CD-Key that is called by the shell during authentication.

In an embodiment of the present invention, to protect a recordable optical disc using the authentication method, a CD publisher provides core data locally and connects remotely to the protection website to run a remote copy of the protection program on the publisher's computer. A fingerprint is determined for the disc and provided to the publisher in the form of a CD-Key. The publisher then stores the disc and the provided CD-Key with other CD-Rs from the same batch for later use. When the publisher requires copies, they re-connect to the protection website to have the data encrypted and a protective shell added to the core data.

In an embodiment of the present invention, the core data is encrypted and the shell added in the same session as performing the fingerprinting. The publisher can then burn customer-ordered copies onto recordable discs from the same batch when needed, providing the CD-Key with the disc delivered to the customer.

Prior art disc protection methods entail slow and laborious steps

employing expensive, high-precision equipment. The invention can provide a disc fingerprint using common, everyday equipment such as a CD-ROM drive-equipped personal computer.

As well, because the difference between disc formats lies in the data within the sectors and not in the way sectors are written to the disc, the invention provides a format-insensitive method of optical disc authentication.

In an embodiment of the present invention, the pre-defined location of ways is the outside edge of the trace to increase accuracy since differences are larger in this location due to error accumulation.

Although the present invention has been described in considerable detail with reference to certain preferred embodiments thereof, other versions are possible. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred embodiments contained herein.